Proposals for measuring transversity distributions in deep inelastic electron scattering and a model for E-704 asymmetries <sup>1</sup>

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## Abstract

We present the principles of the measurement of the quark transversity distributions in semi-inclusive deep inelastic electron scattering, which form the basis of HELP and one of the ELFE proposals. A string model for Collins-type asymmetry in polarized quark fragmentation function is proposed. A possible role of the Collins effect in the single spin asymmetries observed by experiment E 704 at Fermilab is suggested.

Contribution to the V<sup>th</sup> International Workshop on High Energy Spin Physics, SPIN-93, September 20-24, 1993, Protvino, Russia

1. Introduction. At leading twist, the most complete information about the short distance quark structure of the nucleon involves three distribution functions:

$$\Delta q(x) = q_{+}(x) - q_{-}(x) \text{ in a nucleon of helicity } + \frac{1}{2}, \tag{1}$$

$$\Delta_T q(x) = q_{\hat{\mathbf{n}}}(x) - q_{-\hat{\mathbf{n}}}(x) \text{ in a nucleon of transversity } + \hat{\mathbf{n}}, \tag{2}$$

$$q(x) = q_{+}(x) + q_{-}(x) = q_{\hat{\mathbf{n}}}(x) + q_{-\hat{\mathbf{n}}}(x). \tag{3}$$

Recent EMC and SLAC experiments have measured  $g_1(x) = \frac{1}{2} \sum_f e_f^2 \Delta q_f(x)$  but so far no experiment has measured  $\Delta_T q(x)$  (also called  $h_T(x)$ ,  $h_T(x)$ ,  $h_T(x)$ ).

A transversity state is obtained by superposition of two helicity states:

$$|\hat{\mathbf{n}}\rangle = 2^{-1/2} (|+\rangle + \exp(i\phi)|-\rangle),$$
 (4)

where  $\phi$  is the azimuth of  $\hat{\mathbf{n}}$  (this definition applies to massless particles as well). As a general rule, transversity distributions or transverse spin asymmetries can be considered as interferences between helicity amplitudes differing by one unit of helicity. In particular,  $\Delta_T q(x)$  is proportional to the discontinuity of the helicity-flip, forward quark-nucleon scattering amplitude (lower blob of Fig. 1a).

A priori,  $\Delta_T q(x)$  differs from  $\Delta q(x)$  (except in the nonrelativistic quark model). They do not have the same evolution with  $Q^2$ . Gluon distributions do not mix with  $\Delta_T q(x)$ . In a simple covariant (quark + scalar diquark) model of the nucleon,  $\Delta_T q(x)$  is always positive, whereas  $\Delta_T q(x)$  is negative for large enough average intrinsic transverse momentum<sup>2</sup>. Thus  $\Delta_T q(x)$  and  $\Delta q(x)$  contain nonredundant informations about nucleon structure.

2. Helicity selection rules for transversity measurement. If one wants to measure  $\Delta_T q(x)$  in Deep Inelastic Lepton Scattering (DILS) in a fully inclusive way (unitarity diagram of Fig. 1a), one is impeded by the approximate conservation of quark helicity at the electromagnetic vertices. This is not the case in doubly polarized Drell-Yan reaction<sup>1,2</sup> (Fig. 1b), which measures  $\Delta_T q(x)$  in one proton  $\times \Delta_T \bar{q}(x')$  in the other proton. We can generalize these results in a "selection rule" for reactions probing transverse spin at leading twist: in the unitarity diagram, the line of a transversely polarized quark must connect two different hadrons. A list of such reactions is given in Ref<sup>4</sup>.

A doubly polarized Drell-Yan experiment has been proposed for RICH.

**3. Semi-inclusive hyperon production in DILS.** Another probe is obtained from the Drell-Yan one by *crossing*. The prototype of it is<sup>5</sup>

$$e+\uparrow N \to e'+\uparrow \Lambda + X$$
, (5)

where the  $\Lambda$  is emitted in the current fragmentation region. A typical exclusive diagram is shown in Fig. 2 (we choose the  $\Lambda$  because it is the simplest self-analysing hadron but any hyperon could do the job).  $\Delta_T \bar{q}(x')$  is crossed into the transversely polarized fragmentation function  $\Delta_T f_{q \to \Lambda}(z)$ . The polarization of the  $\Lambda$  is given by

$$\vec{\mathcal{P}}_{\perp\Lambda} = \mathcal{R}_{N\Lambda} \ \vec{\mathcal{P}}_{\perp N} \times \hat{D}_{NN}(\hat{\theta}) \times \frac{\sum e_f^2 \Delta_T q_f(x) \Delta_T f_{q_f \to \Lambda}(z)}{\sum e_f^2 q_f(x) f_{q_f \to \Lambda}(z)} \qquad (f = u, d, s, \bar{u}, \bar{d}, \bar{s}), \tag{6}$$

where  $\mathcal{R}_{N\Lambda}$  is the rotation about the normal to the scattering plane which brings the initial nucleon momentum along the  $\Lambda$  one, in the c.m. frame.

$$\hat{D}_{\rm NN}(\hat{\theta}) = \frac{4(1+\cos\hat{\theta})}{4+(1+\cos\hat{\theta})^2} = -2\,\hat{s}\hat{u}/(\hat{s}^2+\hat{u}^2) = 2\,E_e\,E_e'/(E_e^2+{E'}_e^2) \tag{7}$$

is the depolarization parameter of electron-quark scattering.

4. Mesonic polarimeter. In the preceding reaction, the  $\uparrow$  hyperon can be considered as as polarimeter for the scattered quark. But quark fragmentation into hyperon is rather rare, therefore a high number of DILS events is required. Other types of quark polarimeter have been proposed by Nachtmann, Efremov, Collins, which use fragmentation into meson. The Collins one<sup>6</sup> seems the most appropriate to quark transversity. The fragmentation of a quark of polarization  $\vec{\mathcal{P}}$  should have an azimuthal dependance given by

$$f(z, \vec{p}_T, \vec{P}) = f(z, p_T^2) + \Delta_T f(z, p_T^2) \times \mathcal{P}_{\perp} \times \sin\left(\operatorname{azimuth}(\vec{P}) - \operatorname{azimuth}(\vec{p})\right).$$
 (8)

The tensor-polarized fragmentation function  $\hat{h}_{\bar{1}}(z)$  into  $\rho$  meson, introduced by Xiangdong Ji<sup>7</sup>, gives rise to such asymmetry.

- **5. The ELFE**<sup>8</sup> and HELP<sup>9</sup> proposals. Two experiments measuring  $\Delta_T q(x)$  in semi-inclusive DILS have been proposed:
- 1)  $e+\uparrow N \to e'+\uparrow \Lambda + X$ , at the European Laboratory For Electron (ELFE) which is in project. Beam energy: 15 GeV; target: polarized <sup>6</sup>Li d or <sup>6</sup>Li H. A  $4\pi$  detector is envisaged. To fix the ideas, for an integrated luminosity of  $2.5 \times 10^{40}$  cm<sup>-2</sup>, one expects about  $10^5$  lambdas with  $x_F > 0$ , z > 0.3 and  $\langle Q^2 \rangle = 2.0 \,\text{GeV}^2$ . The  $\Lambda$  polarization could reach 0.06 at  $x_{Bj} \simeq 0.2$  and be measured with a precision of 0.01.
- 2) The HELP collaboration proposes to install a hydrogen jet target, 90 % polarized, in the LEP tunnel ( $E_e = 90 \text{ GeV}$ ) in a "parasitic" mode. Target thickness:  $10^{13} \text{ atoms/cm}^2$ . In 6 months, about  $10^4$  lambda should be collected ( $2.2 \cdot 10^3$ ) for  $x_{Bj} > 0.15$ ). In addition, the azimuthal asymmetry in  $e + \uparrow N \rightarrow e' + \text{meson} + X$  (Collins effect) will be investigated, which increases the number of interesting events by more than  $10^2$ .

Such experiments can measure  $\Delta_T q(x)$  and  $\Delta_T f(z)$  (or  $\Delta_T f(z, k_T^2)$  of Eq.(8)) up to normalization factors, since only the product of the two functions appear. Other probes will be necessary to "calibrate" these functions. However, a nonzero signal would be by itself of great significance.

**6. A string model for the Collins effect.** Fig. 4 represent the string pulled in the  $\hat{z}$  direction by a fast quark  $q_0$ , which fragments into a leading pion plus a string remnant. This quark is supposed to have transverse polarization directed toward us  $(s_y(q_0) = +\frac{1}{2})$ . The  $q_1\bar{q}_1$  pair created during string breaking is assumed to be in S=1,  $J^P=0^+$  state (the  $^3P_0$  model<sup>10</sup>).  $q_0$  and  $\bar{q}_1$  must have antiparallel spin in order to form a pion, therefore  $s_y(q_1) = s_y(\bar{q}_1) = -\frac{1}{2}$  and  $L_y(q_1\bar{q}_1) = +1$ . Adopting an idea of the Lund group<sup>11</sup>, this orbital momentum is generated by the tunneling mechanism of quark pair creation:

$$L_y = +\kappa^{-1} \left[ m_q^2 + p_T^2(\bar{q}_1) \right]^{1/2} \times p_x(\bar{q}_1) , \qquad (9)$$

where  $\kappa$  is the string tension. Furthermore,  $p_T(\text{pion}) = p_T(\bar{q}_1) \ (= -p_T(q_1))$ . Thus  $p_x$  of the pion is positive ( $\pm$  some quantum uncertainty).

## 7. Is Collins effect responsible for single spin asymmetry in E 704?

In  $\uparrow p + N \to \pi + X$  at high  $x_F$ , the pion comes more likely from the fragmentation of a valence quark of the proton. If we assume that this quark is polarized like in the SU(6) model and that a string-type Collins effect takes place, we recover<sup>12</sup> the experimental<sup>13</sup> signs of the single spin asymmetries: for upward proton polarization,  $\pi^+$  and  $\pi^0$  are preferentially emitted to the left and  $\pi^-$  to the right. [For  $p_T(\text{pion}) \geq 2 \text{ GeV/c}$ , the valence quark most probably undergoes hard scattering. This results in a reduction of the quark polarization by a factor  $\hat{D}_{NN}(\hat{\theta})$  given by (6) and a smearing of the Collins effect by integration over the hard scattering angle. However,  $\hat{\theta}$  is not very large so that  $\hat{D}_{NN}(\hat{\theta})$  is close to unity. As regards smearing, it is not too severe, due to the "trigger bias" effect.

**8. Conclusion.** Quark transversity is a novel an promising observable for the understanding of hadronic wave function in terms of bare quarks. It is a challenge to make its first measurement. Among various probes, semi-inclusive Deep Inelastic Lepton Scattering is one of the best candidate. The polarization of the scattered quark has to be detected either in the fragmentation into a hyperon or by azimuthal asymmetry of a leading pion (Collins effect). An example of Collins effect is provided by the string model. The later effect may also explain the single spin asymmetries observed in  $\uparrow p + N \to \pi + X$  at high  $x_F$ . If it is the case, the quark transversity distribution in the proton should be large.

## References

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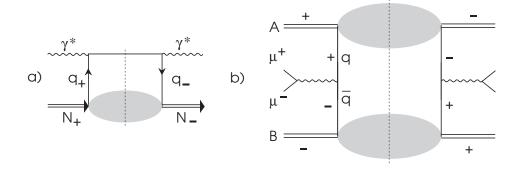


Fig.1

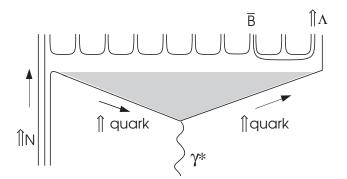


Fig.2

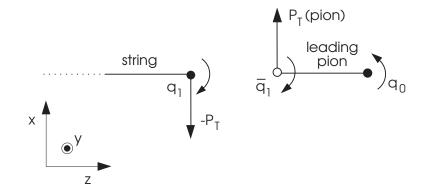


Fig.3